

Quantitative assessment of the impact of NIV chasing on balancing costs

Report by FTI Consulting for NESO

February 2025

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Executive summary

In this report for NESO, FTI quantifies the impact of different levels of NIV chasing activity on BM costs under a national wholesale market design

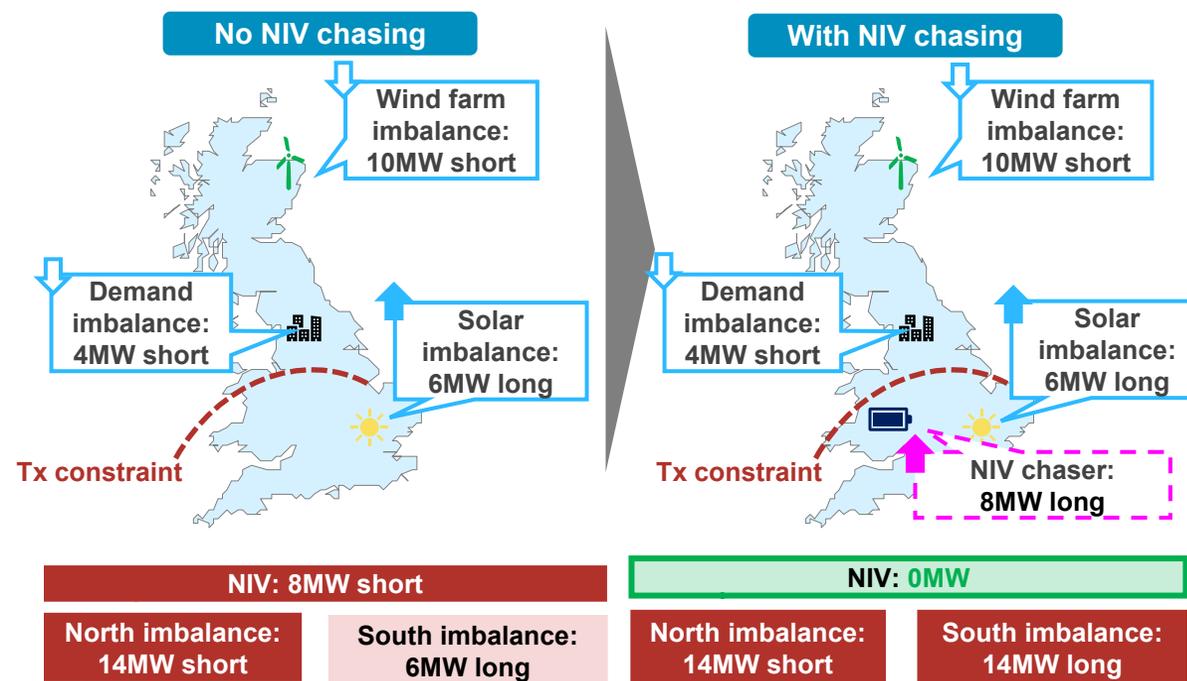
- Following the Autumn Update (2024) of the Review of Electricity Market Arrangements (REMA), the Department for Energy Security and Net Zero (DESNZ) continues evaluating the merits of: (i) zonal wholesale pricing; and (ii) a “reformed” national wholesale market.
- As part of the reformed national market, a return to a dual imbalance price (i.e. a different imbalance price for positive and negative imbalances) is examined. This could significantly reduce the incentives for Net Imbalance Volume (NIV) chasing, i.e. reduce incentives for market participants to be deliberately imbalanced in the opposite direction of the expected Great Britain (GB) -wide NIV.
- In this context, the National Energy System Operator (NESO) has commissioned FTI Consulting LLP (FTI) to quantitatively assess how NIV chasing may impact Balancing Mechanism (BM) costs.
- NIV chasing is expected to **reduce the volume of energy balancing actions** (non-flagged BM actions) but might **increase the volume of system balancing actions** (flagged BM actions) during periods when the single national imbalance price does not reflect local supply-demand conditions due to transmission (Tx) constraints.¹ This dynamic is shown on the right.

This report examines which of the two effects described above is dominant:

Hypothesis 1: *NIV chasers reduce energy balancing costs, and this outweighs any potential negative impact they have on system balancing costs.*

Hypothesis 2: *The potential negative impact of NIV chasing on system balancing costs outweighs the benefit in reducing energy costs.*

Example hour: NIV chasing acting on GB-wide NIV with Tx constraints



In the example above, a Tx constraint between the North and the South means that although NIV chasing reduces the NIV at a GB-level, it exacerbates local imbalances and increases the required volume of flagged BM actions.

Note: (1) We do not quantitatively assess other challenges with NIV chasing such as NIV chasers wrongly anticipating the NIV and NIV chasers collectively ‘overshooting’ the anticipated NIV.

We model three levels of NIV chasing volumes, resulting in three different schedules that are resolved in the BM model with different BM costs

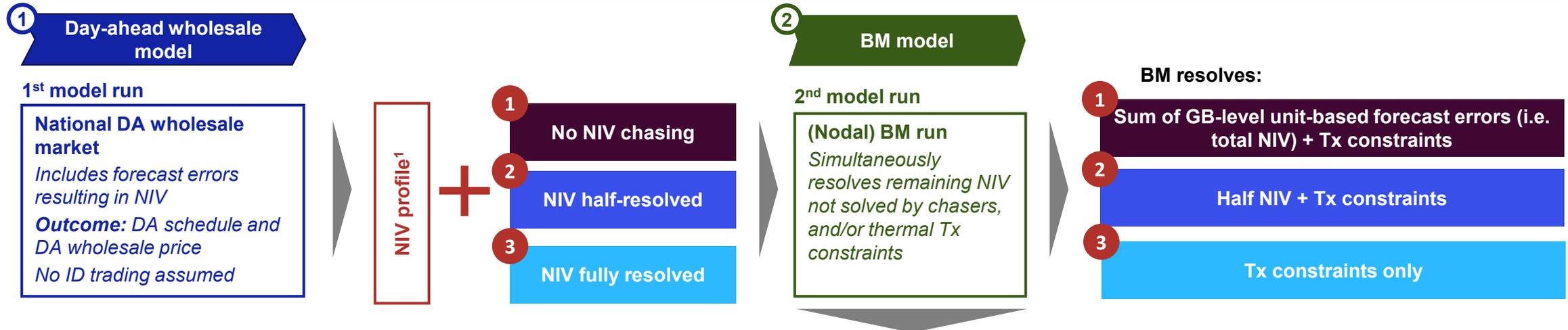
Methodology overview

The assessment first introduces a NIV to be resolved alongside Tx constraints in the BM modelling, formed of post-gate closure time (GCT) forecast errors of wind, solar and load derived from NESO forecast error data. We test how BM volumes and costs change with:

- **No NIV chasing ('0% chase')**: BM resolves net GB energy imbalance (i.e. the NIV) and Tx constraints
- **NIV half-resolved ('50% chase')**: NIV chasers in aggregate resolve half of the GB NIV, with the BM resolving the remaining NIV and Tx constraints (noting the location of the imbalanced units and NIV chasers can impact the system balancing actions)
- **NIV fully resolved ('100% chase')**: BM resolves Tx constraints only (noting the location of the imbalanced units and NIV chasers can impact system balancing actions)

This is summarised in the diagram below. GB generation and demand model inputs follow Clean Power 2030 (CP2030) Further Flex & Renewables (FF&R) (2030), and FES 24 Holistic Transition (2035, 2040), while GB internal Tx follows CP2030 FF&R (2030), and Beyond 2030 (2035, 2040) (see Slide 17 for more detail).

Simplified sequence of modelling process



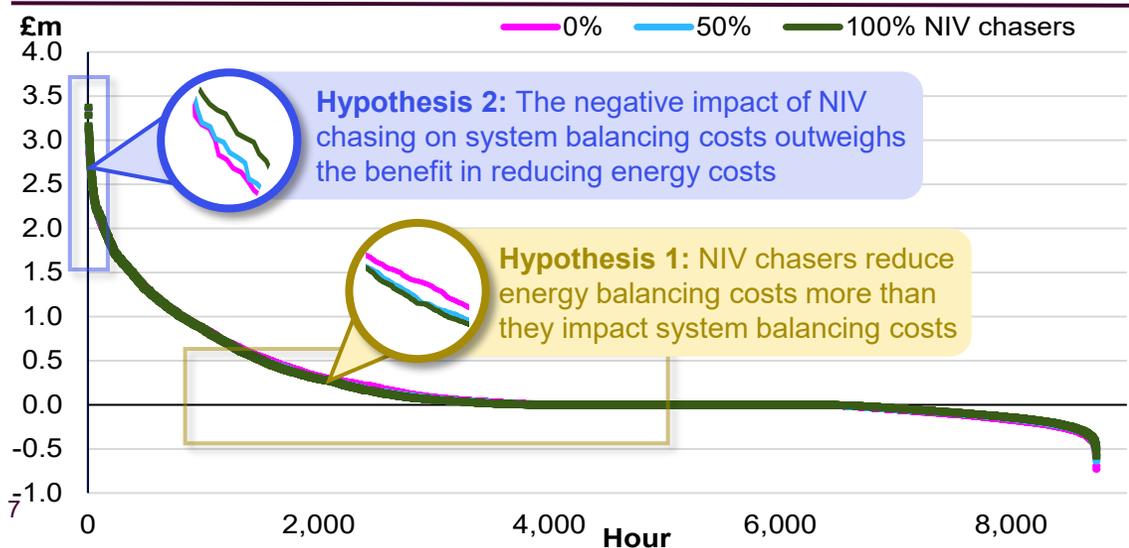
The key output of our analysis is BM costs under three different NIV chasing scenarios, testing a wide envelope of possible NIV chasing activity

6 Note: (1) We define the NIV profile as the unit-based forecast errors in each imbalance settlement period (ISP).

Discouraging NIV chasing under a national wholesale market design could slightly reduce BM costs, but the overall impact on BM costs is minimal

- Our modelling forecasts a significant increase in the cost of balancing actions taken by NESO between 2030 and 2040, independent of the level of NIV chasing.
- **NIV chasing can lower annual BM volumes** by reducing the size of the energy imbalance (by 2-5% per annum under 50% NIV chasing and 2-6% per annum under 100% NIV chasing) – a move to a dual imbalance pricing could likely restrict this effect.
- However, lower BM volumes do not necessarily result in lower BM costs under a single national imbalance price. Instead, **NIV chasing has an ambiguous effect on BM costs. In most modelled years and NIV chasing scenarios, BM costs increase to a very minor extent.**
- This result can be explained by **NIV chasing increasing BM costs in the hours with the highest constrained-on costs.** In those infrequent hours, NIV chasers reacting to a single national imbalance price worsen local imbalances, triggering additional costly system balancing actions. In contrast, **in hours with low yet positive constrained-on costs (i.e., likely hours with low Tx constraints), NIV chasing reduces BM costs.** The overall impact on BM costs approximately nets out across each modelled year.

Duration curve of hourly constrained-on costs (excl. storage), 2035 - 0%, 50% and 100% NIV chasing scenarios (£m)



Total annual BM costs (£m)	2030	2035	2040
0% NIV chasing	2,539	3,321	4,156
50% NIV chasing	+29 ↑	-8 ↓	-31 ↓
100% NIV chasing	+94 ↑	+59 ↑	+12 ↑

↑ Increase relative to 0% NIV chasing ↓ Decrease relative to 0% NIV chasing

Overall conclusions

- Conclusion 1:** *BM costs are forecasted to grow significantly under the current wholesale market design and remain high at £2.5-4.2bn per year.*
- Conclusion 2:** *Both hypotheses tested are found to be correct in different periods: NIV chasing reduces BM costs in some hours (H1), but increases them in other hours by exacerbating Tx constraints (H2). This impact varies over time depending on the location of the NIV itself and on the location of NIV chasers.*
- Conclusion 3:** *Overall, NIV chasing is shown in most (but not all) modelled scenarios to slightly increase BM costs (-£31m to +£94m / year), but this impact is minimal relative to the total projected BM costs (<4% of total BM costs). As such, discouraging NIV chasing as part of a “reformed national market” is not a credible tool for mitigating the projected continuing rise in BM costs in GB under national wholesale pricing.*

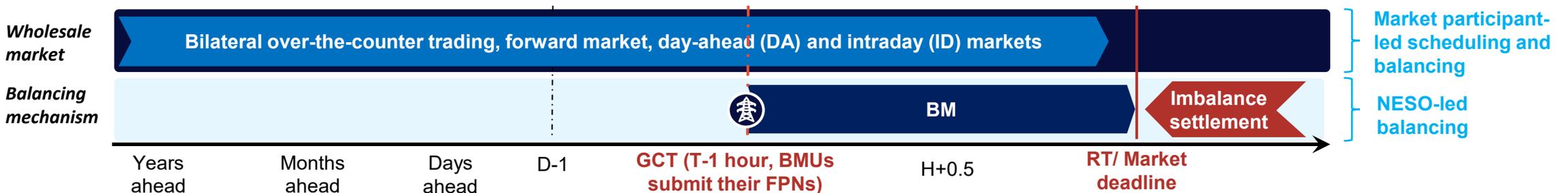
Background and context

Post-Gate Closure Time NESO ensures the safe operation of the power system via energy and system balancing actions

Great Britain (GB) operates a liberalised electricity market designed to incentivise market participants to self-balance their portfolios. Electricity is traded bilaterally through the organised wholesale market covering different forward timeframes. Trading is allowed up to the market deadline taking place at the start of the imbalance settlement period (ISP), i.e. real time (RT). However, Final Physical Notifications (FPNs) must be submitted by Balancing Mechanism Units (BMUs) by gate-closure time (GCT), which occurs one-hour ahead of RT. Post-GCT, the National Energy System Operator (NESO) ensures real-time balance between supply and demand while respecting all security constraints via the Balancing Mechanism (BM). BMUs activated by NESO in the BM are paid their BM offer/bid prices (pay-as-bid). Key features of the existing market design are:

- **National wholesale price.** There is a single national wholesale electricity price per settlement period; across all locations within GB.
- **Single imbalance price.** Market participants both over- and under-delivering in RT relative to their contracted position face the same imbalance price.¹

Simplified schematic of the current GB electricity market design



With a large proportion of electricity traded in forward wholesale markets with a national price, two key issues arise in RT: (i) energy imbalances due to forecast errors or unforeseen outages; and (ii) system imbalances due to security constraints (notably thermal transmission (Tx) limitations within GB) not being reflected in the wholesale schedule. As explained in the boxes below, NESO resolves both types of issue via non-flagged and flagged activations of BMUs in the BM. In practice, both types of actions are performed to some extent jointly.

 **'Non-flagged' actions or energy balancing actions**

The forward nature of wholesale markets (e.g. at DA) means that, due to forecast errors or unforeseen outages, market participants' contractual positions at GCT do not always match the metered generation/consumption of their portfolio in the relevant Imbalance Settlement Period (ISP). Balancing actions are therefore required to restore balance between supply and demand at the GB-aggregate level.

 **'Flagged' actions or system balancing actions**

A national wholesale price assumes an unrestricted 'copper plate' Tx network without any security constraints. In practice, actions in the BM are required for other reasons than balancing supply and demand, for example driven by thermal limits of the Tx network, voltage management or for reasons of system stability.

Notes: (1) The imbalance price is determined by the 1MW of most expensive non-flagged activation within that ISP (see [link](#)). GB switched from a dual imbalance price, i.e. having a different imbalance price for parties being long and short to a single imbalance price in 2015 (see [link](#)). Most EU countries also have a single imbalance price in accordance with Art. 52(2) of the electricity balancing guideline (see [link](#)).

A single imbalance price can incentivise market participants to be deliberately imbalanced in the opposite direction of the net GB imbalance

- If a market participant's metered output within an ISP and contracted position do not match, they are exposed to the imbalance price. The imbalance price reflects the cost of energy balancing actions (non-flagged actions) taken by NESO in the relevant settlement period. Market parties that are long are paid the imbalance price for their additional output, while those short pay the imbalance price. The imbalance price can be positive or negative depending on the direction of the GB-wide Net Imbalance Volume (NIV).
- Due to the last-minute nature of energy balancing actions, the imbalance price is often more volatile than the DA price (see figure below). When the system is short, the imbalance price is often relatively high, with NESO paying units to increase output in the BM. When the system is long, the imbalance price is often relatively low.
- For this reason, under a single imbalance price, market participants can have the incentive to be deliberately imbalanced in the opposite direction of the anticipated GB-level NIV in an ISP. If the direction of the NIV is predicted correctly, imbalanced market participants can receive the relatively high imbalance price when selling power, or pay the relatively low imbalance price when purchasing power. The deliberate choice of being imbalanced in the opposite direction of the NIV is termed '**NIV chasing**'.
- BMUs are required to follow the output indicated in their FPNs submitted at GCT.¹ Although BMUs can still NIV chase post-GCT by altering their contracted position, this inability to unilaterally change their physical position in response to new information gained between GCT and RT likely increases the risk of NIV chasing. Consequently, NIV chasing is assumed to be largely confined to flexible non-BMUs, which do not face the same restrictions on physical output changes post-GCT.
- A dual imbalance price, under which market participants that are long are paid a different imbalance price than a participant that is short, typically discourages NIV chasing. This is because, for example, when the system is short, participants that are short would typically face an imbalance price that reflects the marginal cost of constrained-on actions required to restore the system imbalance, while market parties that are long would be paid a lower imbalance price (and vice versa when the system is long).

Sample of historical GB DA and imbalance prices, October 7th – October 22nd 2024 (£/MWh)

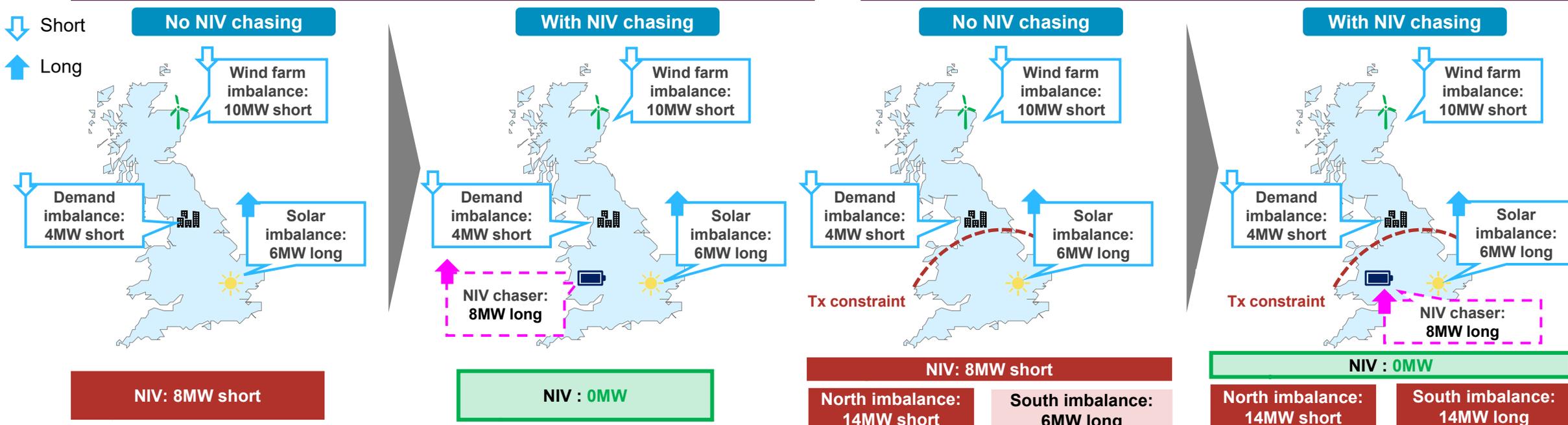


NIV chasing can – in theory – both increase and decrease BM volumes, depending on the presence of Tx constraints

- NIV chasers, by reducing the NIV, can lower the number of non-flagged (energy imbalance) actions required by NESO. The extent to which NIV chasing reduces BM volumes and costs (and hence consumer costs) depends on several factors, including: (i) whether NIV chasers can correctly anticipate the expected direction of the NIV and whether the magnitude of the collective imbalance created by NIV chasers does not exceed the anticipated NIV (i.e. no overshooting)¹; and (ii) whether there are other system constraints, most notably thermal Tx constraints, which would result in a single imbalance price not reflecting local supply-demand imbalances.
- Assuming perfect foresight of NIV chasers, the worked example below shows that, depending on the presence of Tx constraints, a single imbalance price can lead to NIV chasers impacting the volume of flagged (system balancing) BM actions in an ISP (and therefore likely the associated BM costs).

Example hour: NIV chasing acting on GB-wide NIV **without** Tx constraints

Example hour: NIV chasing acting on GB-wide NIV **with** Tx constraints



NIV chasing reduces the NIV for this example hour without Tx constraints...
...reducing the volume of required BM actions.

Assuming a Tx constraint between the North and the South, although NIV chasing reduces the NIV at GB-level, it exacerbates local imbalances ...
... increasing the volume of required flagged BM actions.

The merits of NIV chasing are being examined as part of REMA; FTI has been commissioned to examine impacts on BM costs

- In the Autumn Update (2024) of the Review of Electricity Market Arrangements (REMA), no final decision was taken between: (i) zonal wholesale pricing; or (ii) a “reformed” national wholesale market.¹ Both options are being examined in detail, and additional evidence is being collected on their merits.
- Incremental reforms to the BM are proposed as part of the reformed national wholesale market option. The REMA Autumn update indicates that while these potential BM reforms are expected to deliver “*more limited benefits relative to the operational challenges in the market and compared to zonal pricing*”, they need to be subjected to further assessment.²
- One of the proposed reforms to the BM, while not directly impacting the design of the BM itself but rather indirectly impacting BM volumes, is a return to a dual imbalance price (i.e. a different imbalance price for market parties being short and long). This reform could significantly reduce the incentives for NIV chasing. In this context, the Department for Energy Security and Net Zero (DESNZ) is seeking to understand how NIV chasing may impact outcomes for consumers, and specifically to examine how NIV chasing could impact the management of intra-GB congestion. There are two specific hypothesised concerns in relation to NIV chasing:

NIV chasers, even when perfectly anticipating the GB-wide imbalance, could **exacerbate local network congestion, and therefore increase consumer costs.**

NIV chasing can lead to uncertainty for NESO on the level of system support balancing by non-BM resources. This relates to NIV chasers imperfectly anticipating the direction of the NIV and/or collectively ‘overshooting’ the NIV.³

Outlined in the previous slide, and the focus of this report

Not examined in this report

- **FTI Consulting LLP (FTI) has been commissioned to quantitatively assess** the impact of NIV chasing on regional imbalances and subsequent changes to BM costs.
- In this report, we assess the extent to which different degrees of NIV chasing by market participants impact on BM volumes and costs, assuming the national market design is kept in place. We do not examine the impact of NIV chasing under a potential zonal market design.
- Specifically, this report examines which of the two effects outlined in the previous slide is dominant:
 1. **Hypothesis 1:** NIV chasers reduce energy balancing costs (i.e. GB-wide imbalance), and this outweighs any potential negative impact they have on system balancing costs (i.e. network congestion driving local imbalance); or
 2. **Hypothesis 2:** The potential negative impact of NIV chasing on system balancing costs outweighs their benefit in reducing energy balancing costs.
- The assessment focuses on the impact on BM costs only, and does not consider other potential benefits or risks of NIV chasing, nor other types of consumer costs it may impact (for example, residual cashflows from imbalance settlements or Contract for Difference (CfD) payments (see Appendix)).

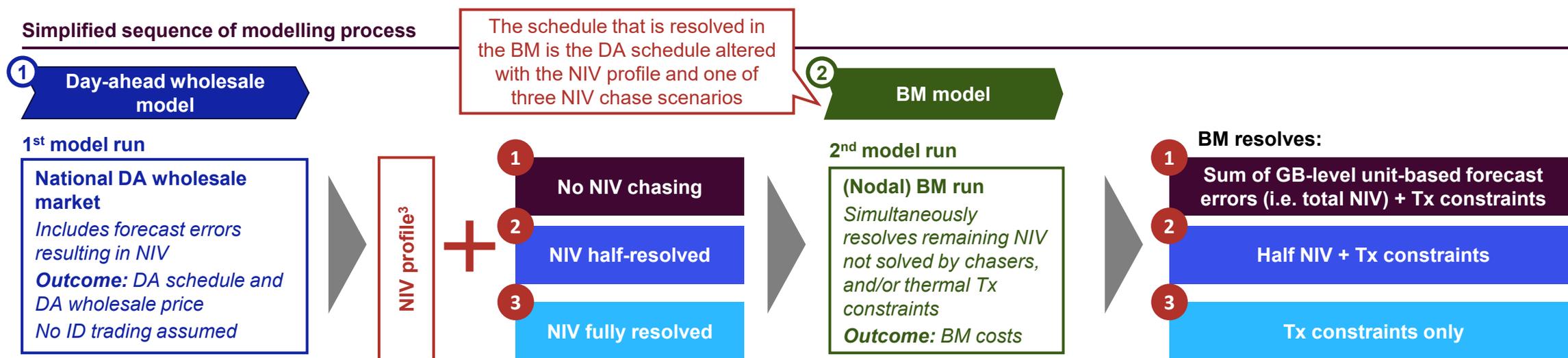
Sources/notes: (1) Review of Electricity Market Arrangements – Autumn Update, Department for Energy Security & Net Zero (DESNZ), December 2024, p16/17 ([link](#)); (2) Ibid, p28; (3) The Netherlands has ‘hybrid imbalance pricing’ in place with: (i) a single imbalance price in ISPs where the Transmission System Operator (TSO) only activates balancing resources in one direction; and (ii) a dual imbalance price in ISPs where the TSO is activating both ‘balancing up’ and ‘balancing down’ resources. The main cited reason to have such hybrid system is to ‘temper’ NIV chasing in settlement periods where NIV chasers ‘overshooting’ leads to NIV chasers aggravating the final imbalance volume ([link](#), [link](#)).

Methodology and key input assumptions

We model three levels of NIV chasing volumes resulting in three different schedules that are resolved in our BM model

Our assessment follows a two-step modelling process:

- ① **DA national wholesale market:** ignoring intra-GB Tx constraints, the DA market considers all unit bids and offers to determine the least-cost DA schedule and (pay-as-clear) wholesale price. For simplicity, we assume no ID trading, i.e. the modelled schedule at GCT is the same as at DA.
- ② **BM:** the modelled BM jointly resolves thermal Tx constraints and any energy imbalances created by post-GCT forecast errors of wind, solar or demand.
 - The objective of the modelled BM is to minimise BM costs¹ incurred while ensuring the system remains in balance and respects all thermal Tx constraints, with BM actions remunerated as pay-as-bid. BM costs are assumed to be passed through to consumers.
 - Three NIV chasing scenarios are included. Depending on the modelled NIV chasing scenario, the schedule that is used as an input in the BM is different, as depicted below.² Consequently, NIV chasing alters energy balancing and/or system balancing actions in the BM and therefore can indirectly impact BM costs.



Notes: (1) This is modelled by calculating unit-level BM constrained-on and -off volumes through a comparison of: (i) the positions of assets at GCT, and; (ii) the position of assets in RT, i.e. resulting from a (nodal) model run for which their position at GCT serves as an input and the NIV and/or potential Tx violations need to be resolved. Inflexible assets are fixed to their DA schedule in this nodal run. Changes in an asset's position due to NESO-led BM actions and/or the unit's post-GCT forecast error are separated out and priced accordingly. For more detail see Slide 17 and Appendix. BM bid/offer price assumptions are shown in Slide 20; (2) For simplicity we do not model NIV chasing occurring simultaneously with BM activations by NESO. Instead, the sequence of events modelled are: (i) Grid Supply Point (GSP) -level forecast errors are corrected in the DA schedule at GCT introducing a NIV; (ii) 'Immediate' NIV chaser reactions based on the NIV result in potential changes in GSP-level demand imbalances, altering the schedule created in step (i); (iii) BM activations by NESO resolving the NIV and potential Tx constraints from the schedule resulting from step (ii); (3) We define the NIV profile as the unit-based forecast errors in each ISP (see Slides 22-26 for further detail).

Modelling approach and key input assumptions

We model a nodal-level representation of GB on the Plexos Integrated Energy Model platform

Overview of key input assumptions

- 1 Demand**
 Includes hourly demand profile and flexibility assumptions
- 2 Generation capacity**
 Includes build-out assumptions, plant technical characteristics and Renewable Energy Sources (RES) capacity profiles
- 3 Commodity prices**
 Includes price projections for a set of commodities (CO₂, natural gas, etc.)
- 4 Interconnectors (ICs)**
 ICs connecting to GB and between European bidding zones
- 5 BM-specific input: GB Tx and BM bids/offers**
 Includes over 1,200 Tx nodes in GB, current & future GB network topology with seasonal availability and assumptions on BM bid and offer prices and BM capacity constraints
- 6 Post-processing: CfD and Renewable Obligation Certificates (ROCs) payouts**
 Includes projected CfD/ROC capacity and future regime design including ROC prices, CfD strike price levels and duration

Power Market Model



Day-ahead wholesale model

Takes capacity as given and determines optimal output of generation and storage (GWh):

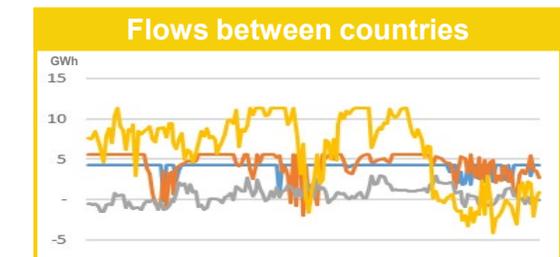
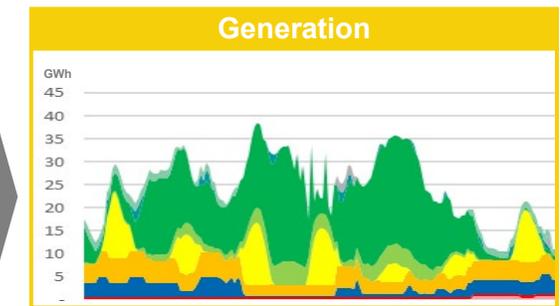
- Finds the least-cost dispatch profile of generation/storage that meets demand...
- ...on an hourly basis...
- ...for each generating plant and storage unit¹...
- ...subject to generator maintenance & outages...
- ...but ignoring any potential intra-GB Tx violation (under national wholesale pricing)

BM model

Introduces nodal-level representation of the GB Tx network:

- Uses dispatch profile from the day-ahead model...
- ...adding unit-level forecast errors at GCT and potentially Grid Supply Point (GSP) -level NIV chasing volumes...
- ...and re-optimises dispatch respecting nodal intra-GB Tx constraints while resolving the NIV...
- ...using technology-specific bid and offer assumptions...
- ...with demand and certain generation technologies (e.g. nuclear) fixed to their day-ahead position.

Example outputs



Key modelling assumptions were developed in collaboration with NESO and DESNZ

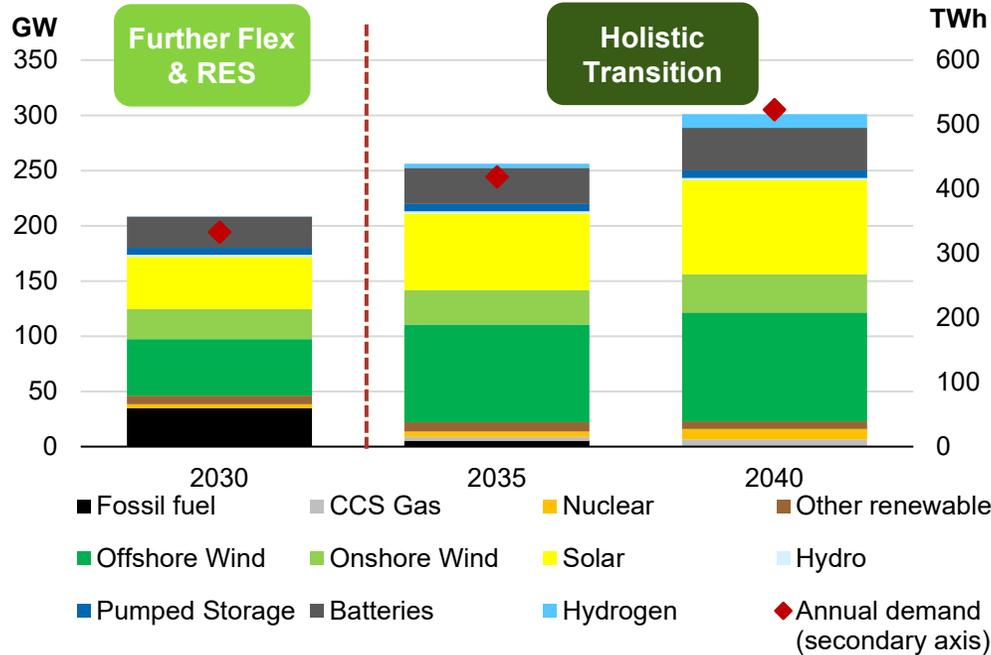
- Key modelling assumptions used in our quantitative analysis are presented in the table below.
- These have been developed through extensive engagement with NESO and DESNZ, and we understand that, where possible, these reflect the same assumptions as in other quantitative assessments performed by DESNZ within the wider REMA process.

Assumption		Detailed description
GB generation capacity & demand		Clean Power 2030 (CP2030) Further Flex & Renewables (FF&R) / Future Energy Scenarios (FES) 2024 Holistic Transition (HT)
GB ICs		Assumed operational interconnectors aligned with DESNZ REMA IC assumptions
Europe generation capacity, demand, and interconnectors		Ten-Year Network Development Plan (TYNDP) 24 Distributed Energy (DE)^{1,2}
Commodity prices		Natural gas, hydrogen, oil and coal prices follow DESNZ 2024 projections Biomass and waste price calibrated using FES 2024 forecast capacity factors Carbon price aligned with FES 24 HT
Modelled years		2030, 2035, 2040
Climate year (CY)		CY2013³
Tx network ¹		CP2030 and Beyond 2030
BM participation and pricing		Participating technologies and pricing agreed in collaboration with NESO and Ofgem Penalty price for interconnector redispatch aligned with forecasted bid/offer prices provided by NESO
Forecast error		Demand: calculated from national aggregate imbalance and sample of GSP-level forecast errors (provided by NESO) Wind: calculated using DA forecast and FPN by windfarm (provided by NESO) Solar: calculated using DA forecast data from NESO and outturn data from Sheffield Solar ⁴ Scalar: DA imbalances scaled down using historical NIV (data provided by NESO)

Note: (1) As TYNDP 24 DE does not have forecasts for 2030, we rely on a mix of TYNDP 24 National Trends (NT) and European Resource Adequacy Assessment (ERAA) 2023 for 2030; (2) When calibrating our model, we identified minor issues with the TYNDP data and have adjusted the assumptions where appropriate following discussion with the European Network of Transmission System Operators for Electricity (ENTSO-E). We do not expect these adjustments to materially affect the conclusions of our modelling; (3) CY2013 is selected to align with NESO's choice of climate year used in the FES and Network Options Assessment (NOA) modelling exercises; (4) Sheffield Solar is a research group with a long-standing collaboration with NESO measuring national and regional solar outturn.

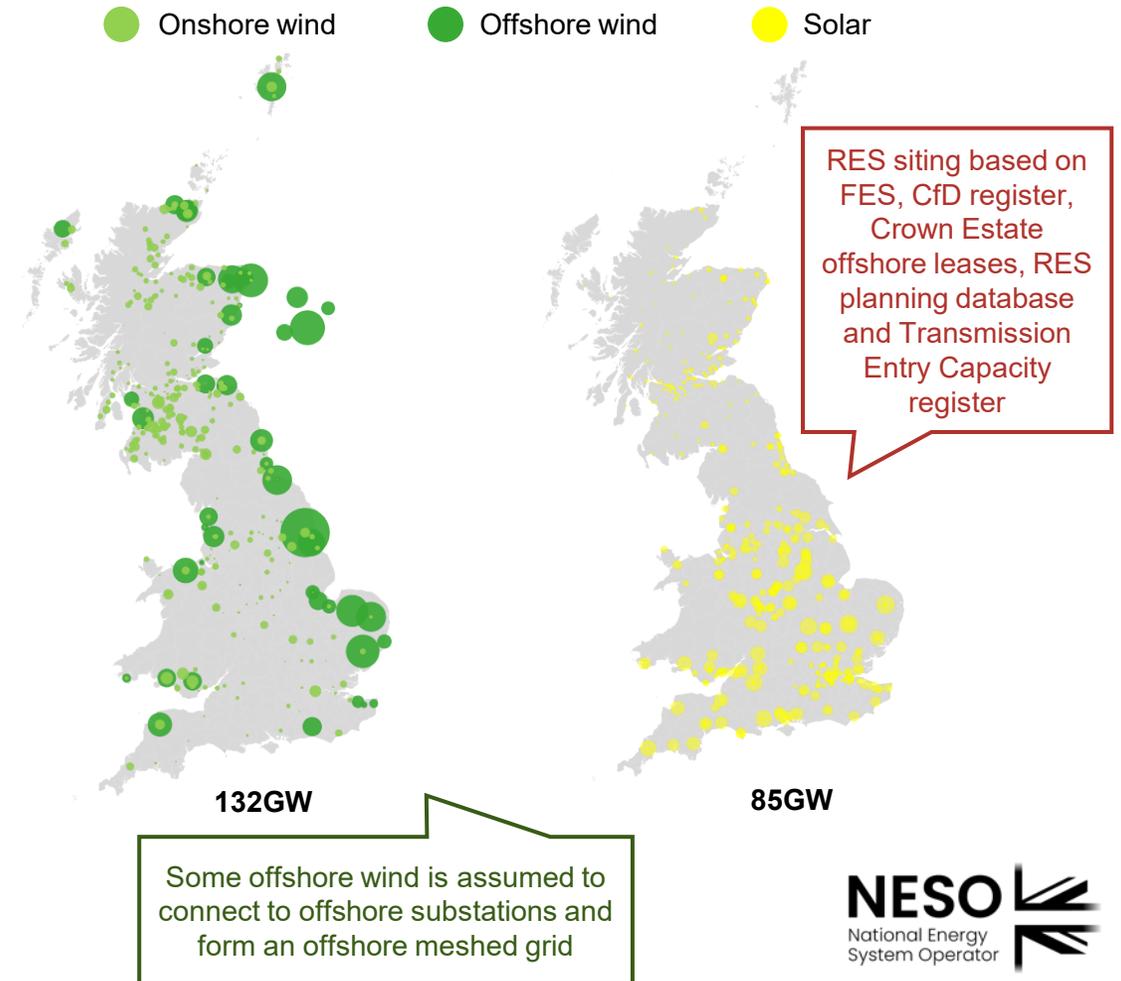
RES capacity increases over the modelling horizon to meet increased demand from electrification, replacing fossil fuels

Installed generation capacity (GW) and annual demand (TWh), GB



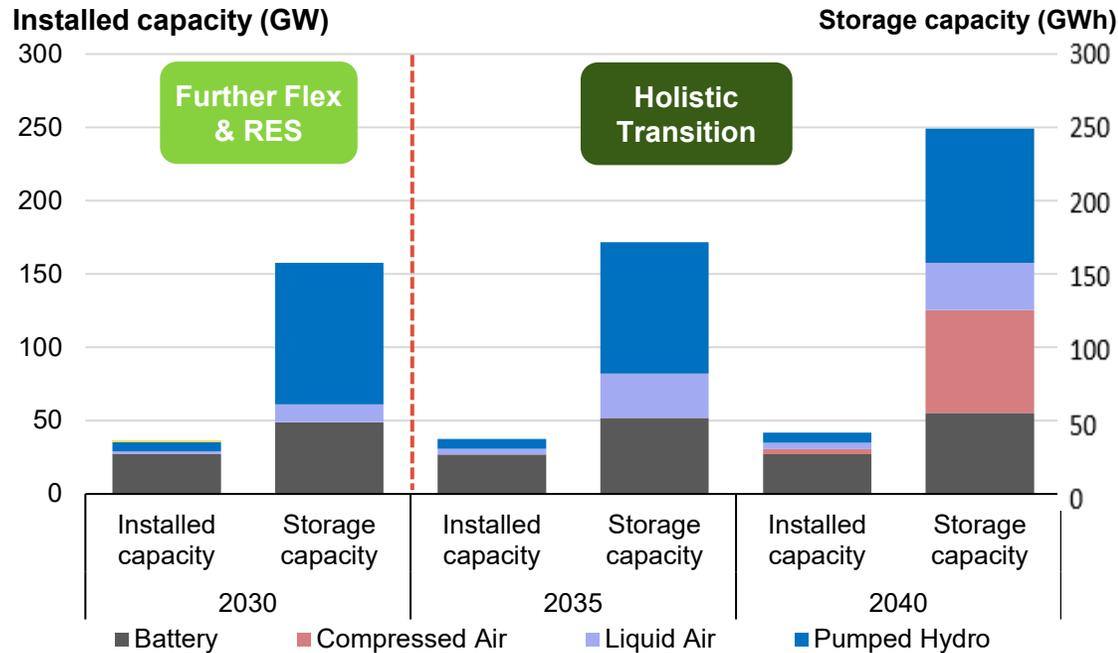
- Generation capacity assumptions follow CP2030 FF&R in 2030, which assumes extensive offshore wind rollout and swift unabated gas phase-out.
- Post-2035, the scenario follows the FES 24 HT (Net Zero) scenario....
- ...which has a steady build-out of RES and total phase-out of unabated fossil fuels.

Assumed location of RES capacity, 2040¹

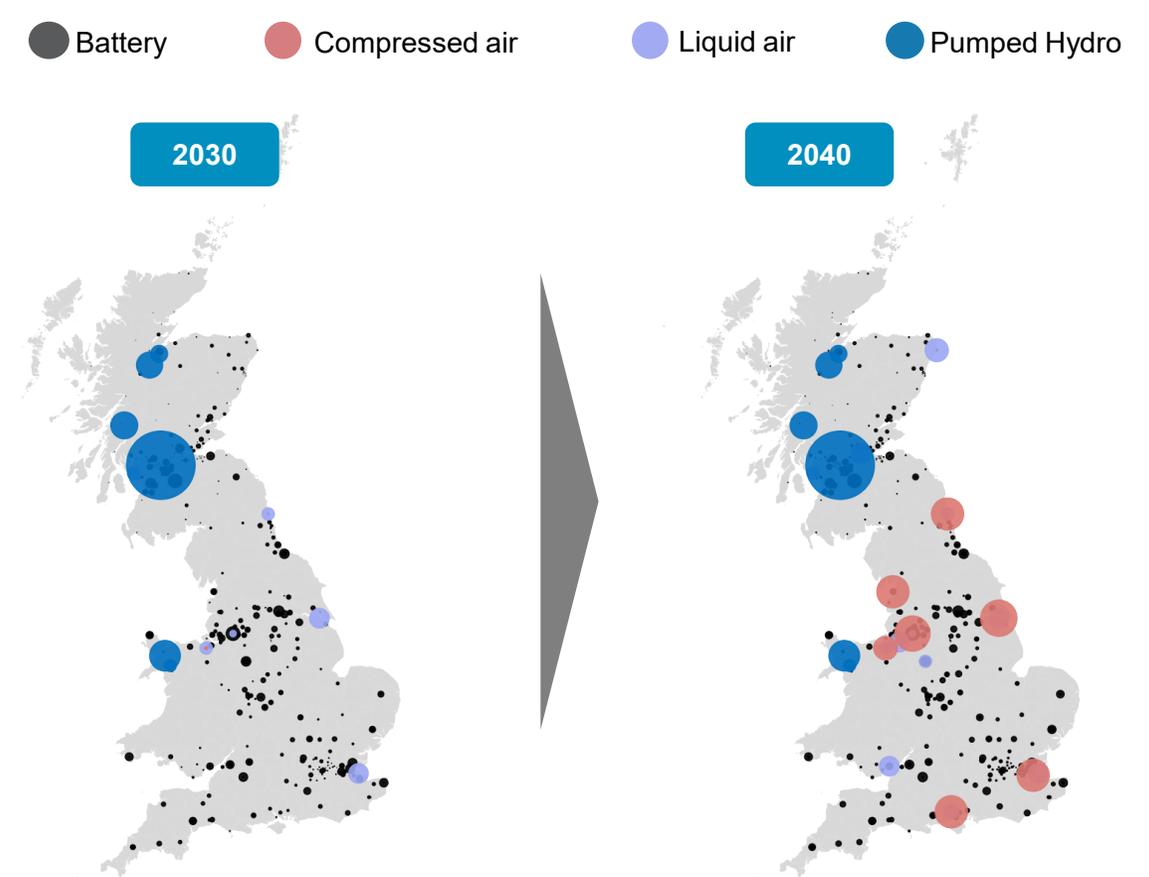


Storage capacity increases over time with the introduction of new technologies (compressed and liquid air)

Storage capacity by technology, GB (GW, GWh)



Assumed location of storage capacity, 2030 and 2040¹



- The majority of installed capacity is made up of utility batteries, although these are relatively low duration and make up a smaller proportion of storage capacity.
- On the other hand, pumped hydro (and in later years liquid and compressed air storage) has limited installed capacity but high storage capacity.
- As discussed further on Slide 29, based on discussions with NESO and given the limited data available on historical NIV chasing, we have assumed in the modelling that only a subset of utility batteries, specifically distribution-connected batteries, can participate in NIV chasing.²

¹⁹ Note: (1) Size of the discs indicates the level of capacity in a particular location. (2) As set out in Slide 29, the key impact of this assumption in the modelling is where NIV chasing is most likely to take place on the GB network. The forecasted aggregate GB NIV and the spatial distribution of imbalances are derived from an analysis of historical NESO data of demand and RES forecast errors.

BM participating technologies and corresponding bid/offer prices were formulated in collaboration with NESO

Bid/offer prices used in BM model

Technology	Cost to NESO	
	Bid (constrained off)	Offer (constrained on)
Fossil fuel 	- Short-run Marginal Cost (SRMC) ¹	Offer uplift + SRMC
ROC renewables 	ROC price	Offer uplift
Merchant renewables 	£0	Offer uplift
CfD renewables 	CfD strike price – Wholesale price	Offer uplift - CfD strike price
Batteries/ Other storage ² 	- Price Paid	Offer uplift + Price Received ³
Interconnectors 	Cost of reversing flow to export	Cost of reversing flow to import
Biomass 	- SRMC	Offer uplift + SRMC
Hydro (run-of-river) 	£0 (but bids only clear after merchant RES)	Assumed not possible

Technologies not listed are assumed not to participate in our BM

- The table to the left shows assumed bid and offer prices for different technologies in the BM, formulated in agreement with NESO.
- Offer uplifts are applied to some technologies representing specific costs and the last-minute nature of the BM (but potentially also capturing historical market power).
- Uplifts are aligned with average historical uplifts using data provided by NESO.
- We assume no bid uplifts, implicitly assuming minimal operational cost of turn-down for units in the BM. This is a conservative assumption for the net cost to NESO of BM actions. Applying bid uplifts would be expected to increase modelled BM costs.
- IC flow reversals are modelled endogenously, with the cost to redispatch an IC calculated using an annual average of monthly NESO forecasts (which consider the cost of the marginal plant in the connected country).

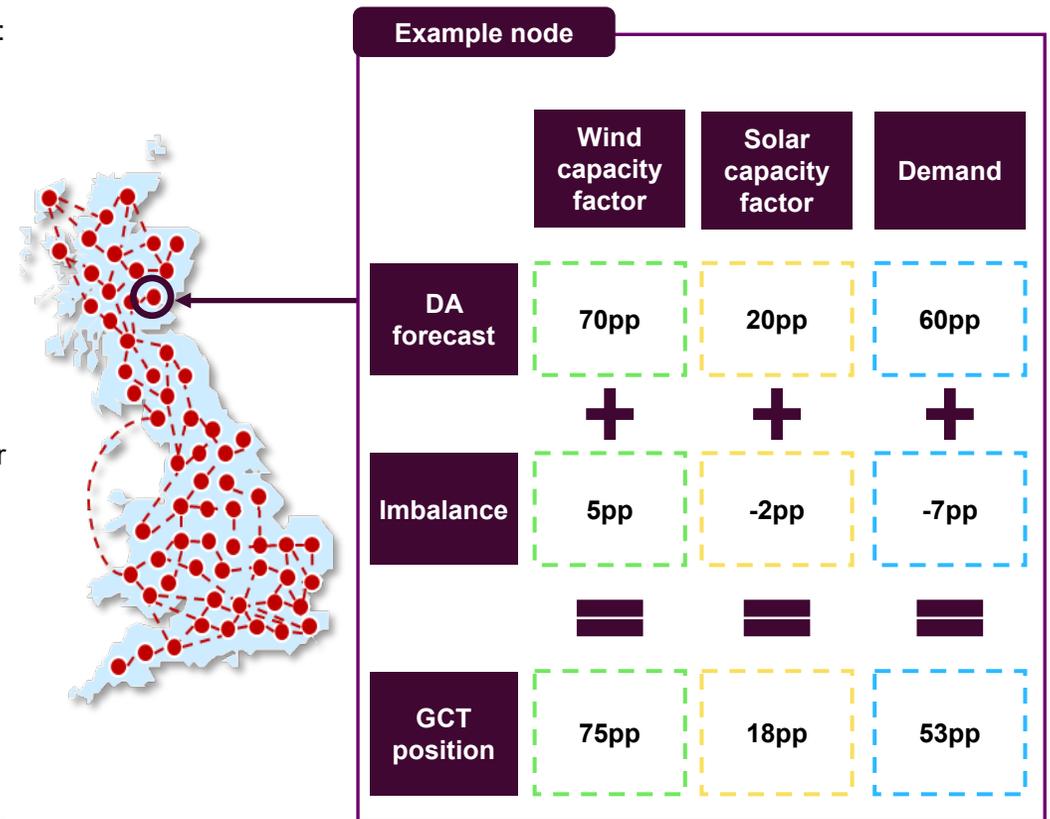
Creation of NIV profiles at GCT

GSP-level forecast errors between GCT and RT have been constructed using NESO data

Differences between contracted and metered volumes result in a NIV across GB, primarily driven by intermittent RES output and mis-forecasting of demand

- Before being able to assess the impact of NIV chasing, we first need to calibrate GSP-level imbalances between GCT and RT (i.e. the NIV). We introduce three sources of forecast errors: wind, solar and GSP-level demand.
- NESO provided the following data used to construct appropriate NIV profiles:
 - For wind, NESO DA forecast and FPN by wind farm;
 - For demand, historical national aggregate imbalance and a sample of GSP-level demand forecast errors between DA and RT;
 - For solar, DA forecasts and outturn data by Distribution Network Operator (DNO) region; and
 - Historical NIV profile from 2024 used for calibration.
- In collaboration with NESO, we have selected the most representative forecast error profiles from the respective datasets and developed locationally-differentiated forecast error profiles for assets of each type on an hourly basis.¹
- Importantly, the forecast error profiles, i.e. the historically observed percentage point differences between DA forecast and final output/load for each asset, remain constant across the modelling horizon. This implies that we assume no change in ability to forecast output/load over time.
- Due to limited availability of data covering the period between GCT and RT, the data provided by NESO relates to the (much longer) DA to GCT/RT period, which is significantly longer than the period relevant to the NIV (forecast errors between GCT and RT). Therefore, it was necessary to scale down the historical forecast errors, such that the average hourly modelled NIV was equal to the average historical NIV seen in the NESO data (adjusting for differences in capacity) – more details about the scaling process are provided in Slides 23-26.

Illustrative application of error profiles at an example GSP/node



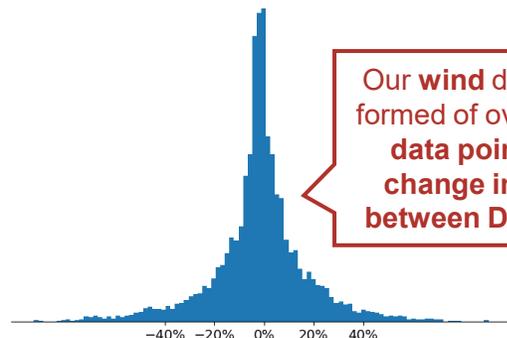
Note: (1) Forecast error profiles for some solar DNO regions and wind GSPs appeared to show structurally biased errors, seemingly primarily driven by mid-year changes in installed capacity within the relevant regions being reflected at different points in time in each dataset. We worked with NESO to select the most representative forecast error profiles from the relevant datasets and excluded DNO regions and wind GSPs with clear structural biases from the sampling database.

We developed DA to RT GSP-level forecast errors for wind, solar and demand

- Below we show histograms of percentage point forecast errors for: (i) wind; (ii) solar; and (iii) demand, constructed using historical data.
- The percentage point errors represent the incremental/decremental change from: (i) DA to GCT for wind¹; and (ii) from DA to RT for solar and demand.²

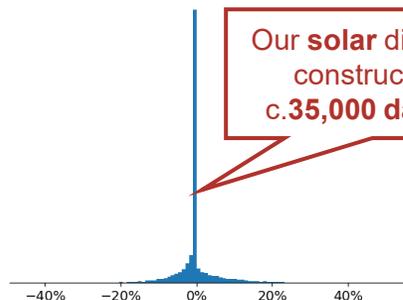
Histograms showing the distribution of samples used to form the wind, solar, and demand imbalance profiles

Wind
(% of GSP capacity)



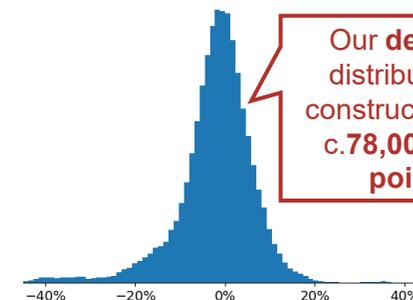
Our **wind** distribution is formed of over **1 million data points** on the change in forecast between DA and GCT

Solar
(% of DNO capacity)



Our **solar** distribution is constructed from **c.35,000 data points**

Demand
(% of GSP peak demand)



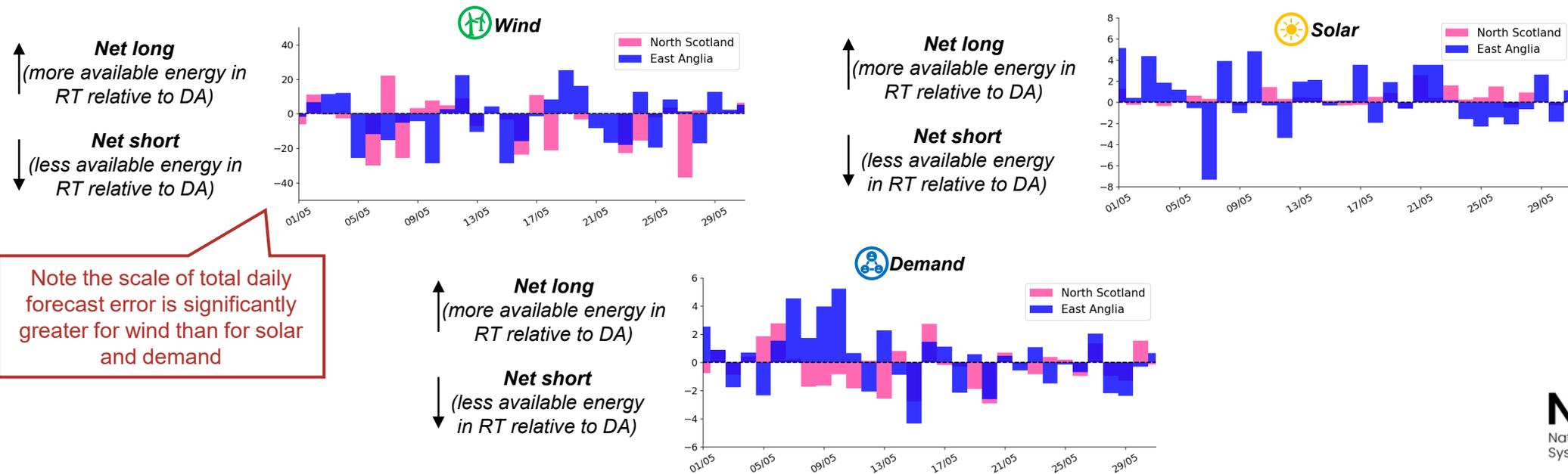
Our **demand** distribution is constructed from **c.78,000 data points**

- For wind, we estimate a historical error profile for each windfarm based on NESO's DA forecast for that asset and Elexon's FPN data for the whole of 2023.
- We map each windfarm to its nearest GSP and calculate a GSP-level wind error profile.
- For each modelled windfarm, we apply the GSP-level imbalance profile from one of the five GSPs closest to the asset from a sample of 26 GSPs.
- Wind errors show the widest variation, with errors in a settlement period regularly exceeding 20pp of installed capacity.
- For solar, we estimate DNO-level error profiles by comparing NESO's forecasts close to the DA auction time with outturn solar modelled by Sheffield Solar (using data from the whole of 2023).
- Structural data biases mean that only two DNOs were deemed to have representative error profiles.
- For each GB zone, we construct an annual solar error profile by sampling daily error profiles from one of the two DNOs in the relevant season to preserve time-of-day and seasonal trends.
- Solar errors show relatively little variation, mostly clustered between +/-10pp of installed capacity.
- For demand, NESO provided DA forecast and actual demand for 11 'demand-dominated' nodes (i.e. with limited embedded generation) for March-Sept 2024.
- For each modelled GSP, we randomly sample errors from these 11 profiles, clustering the sampling regionally and adjusting to ensure consistency with the historically observed net GB imbalance.
- Overall, demand errors are generally clustered between +/-20pp of peak demand.

DA to RT wind forecast errors significantly outweigh solar and demand forecast errors

- As shown in the figures below, the size and direction of historical forecast errors vary significantly across settlement periods and regions.
- The aggregate wind forecast error is an order of magnitude greater than for solar and demand. This can be explained by the combination of high installed wind capacity (see Slide 18), relatively large forecast errors for wind (see previous slide), and relatively high spatial correlation of wind errors.
- Forecast errors for demand, solar and wind can act in the same or opposite directions (as shown in the graphs below for North Scotland and East Anglia), with no discernible pattern.
- In hours where forecast errors act in the same direction, the volume of energy balancing BM actions can be relatively high. For example, hours where the system is significantly short post-GCT due to an over-forecast of wind at GCT and an under-forecast of demand can have high constrained-on volumes. When significant Tx constraints are present in the DA schedule, the impact of forecast errors on balancing volumes will vary depending on the location of the imbalanced units.

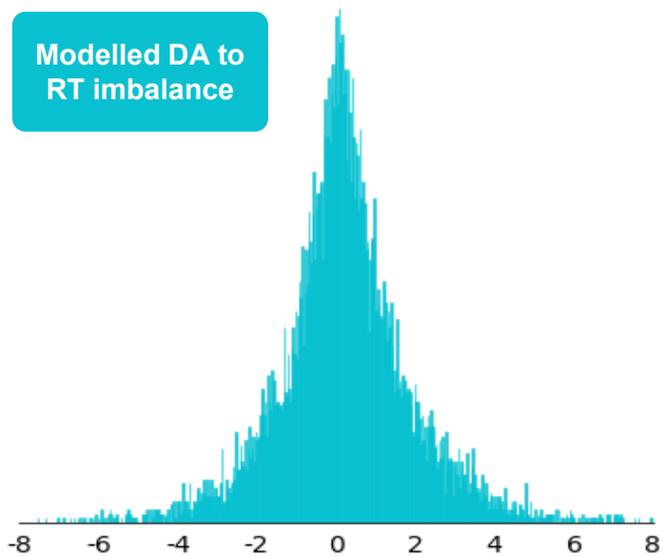
Total daily forecast errors for wind, solar and demand in North Scotland and East Anglia, May 2030 (GW)



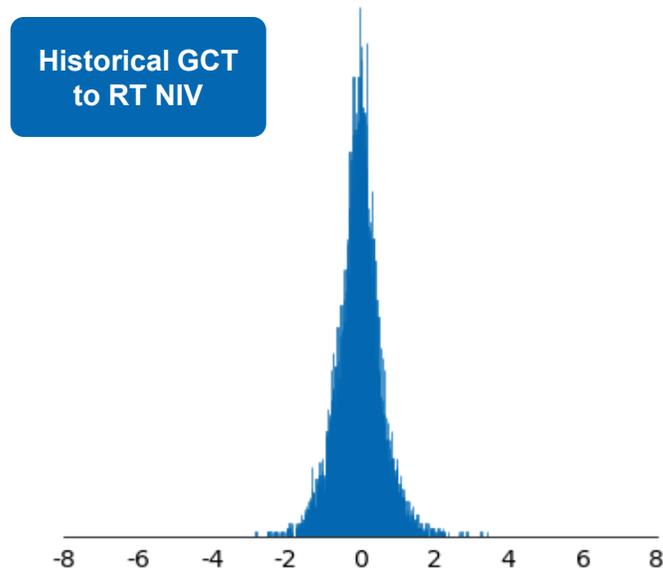
Scaling the DA to RT modelled imbalance profile down by 3.8x provides a similar distribution to the historical 2024 NIV

- Due to the much longer time horizon covered by the NESO forecast error data (DA to RT, rather than GCT to RT), the average hourly GB-level imbalance calculated using the NESO data is significantly larger than the historical aggregate GB NIV.
- We therefore scale down the DA to RT forecast error profile such that the average hourly modelled NIV is equal to the average historically observed aggregate GB NIV in 2024. This scaling factor, calculated as 3.8x, ensures the average net GB imbalance is equal between the modelled NIV profile and the historical NIV profile.
- The distribution of the modelled NIV is very similar to that of the historical NIV profile, providing confidence that the approach provides a reasonable NIV profile approximation.
- Note that by matching the average hourly modelled NIV to the historical NIV, we implicitly assume no NIV chasing in the historical profile. To the extent that NIV chasing impacts the historically observed NIV, the size of our modelled 'pre-NIV chasing' NIV may be biased downwards.

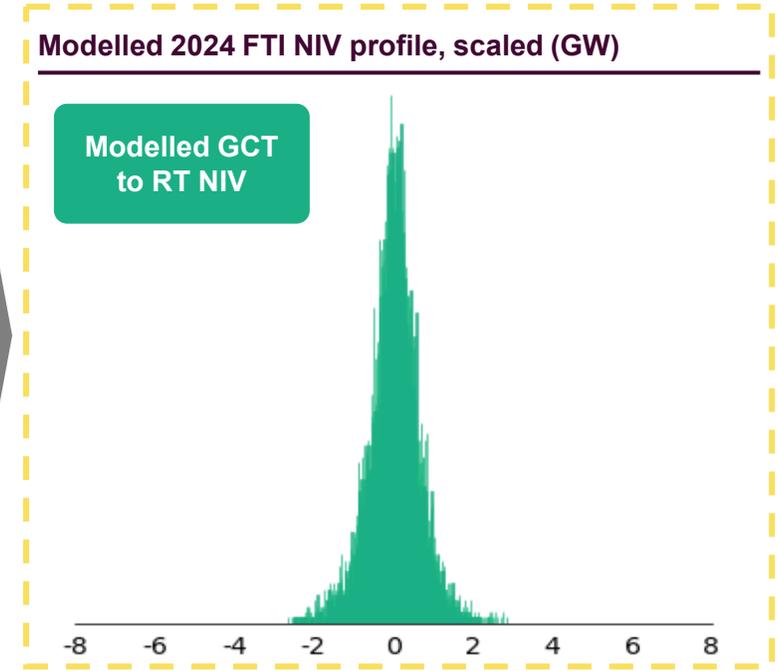
Distribution of FTI DA to RT forecast error imbalance adjusted to 2024 RES + load (GW)



Distribution of NESO historical NIV, 2024 (GW)



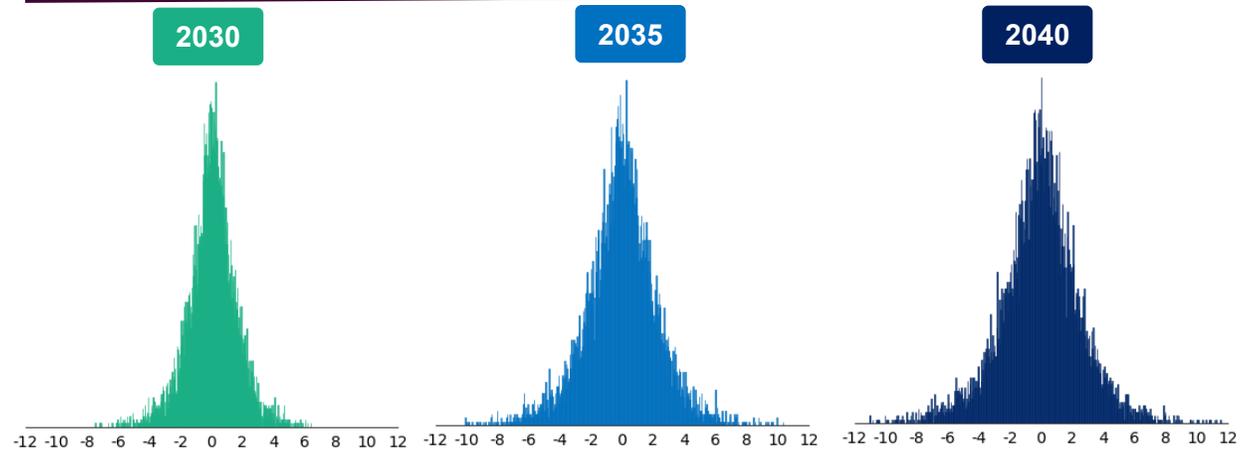
Modelled 2024 FTI NIV profile, scaled (GW)



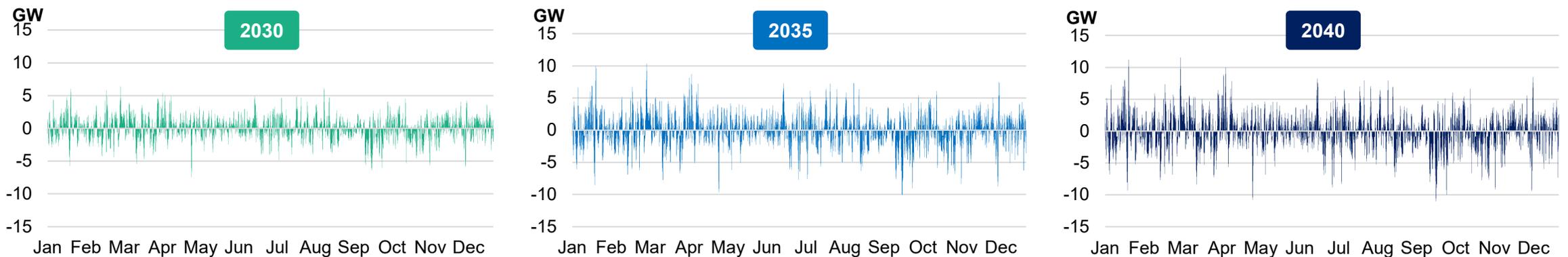
Using the DA to RT GSP-level forecast error profiles and the 3.8x scaling factor, we constructed NIV profiles for 2030 - 2040

- The process to create the 2030, 2035, and 2040 NIV profiles was the following:
 1. Calibrating the DA to RT GSP-level percentage point forecast error profiles described in Slide 25 with the installed wind, solar and demand in 2030, 2035 and 2040 (see Slide 18 for installed capacities in each year);
 2. Scaling down the DA to RT forecast errors per GSP with the 3.8x scaling factor to reflect the shorter GCT to RT time horizon (calculation described in the previous slide).
- The hourly NIV equals the sum of the hourly GSP-level forecast errors across GB.¹
- On the right we show the distribution of the GB NIV for 2030, 2035 and 2040, while below we show the timeseries for the same.
- The NIV increases over time as more wind and solar is installed and demand grows.

Distribution of the modelled GB NIV for 2030, 2035 and 2040 (GW)



Hourly timeseries of the modelled GB NIV for 2030, 2035 and 2040 (GW)²

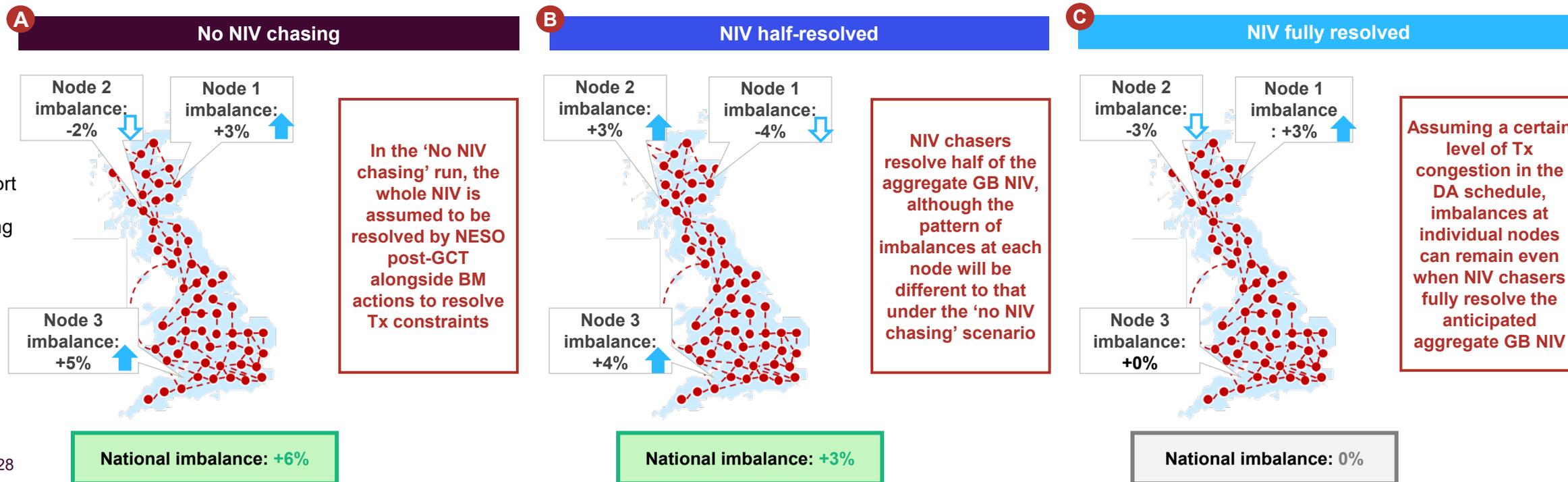


Note: (1) The hourly GSP-level forecast errors are used to calibrate the schedule that is resolved in the BM model (see Slide 22); (2) The hourly timeseries of the modelled NIV varies in magnitude across years due to differing RES capacities/demand, but uses the same historical data (e.g., climate year and forecast error profiles) such that the shape is unchanged across modelled years.

Calibration of NIV chasing

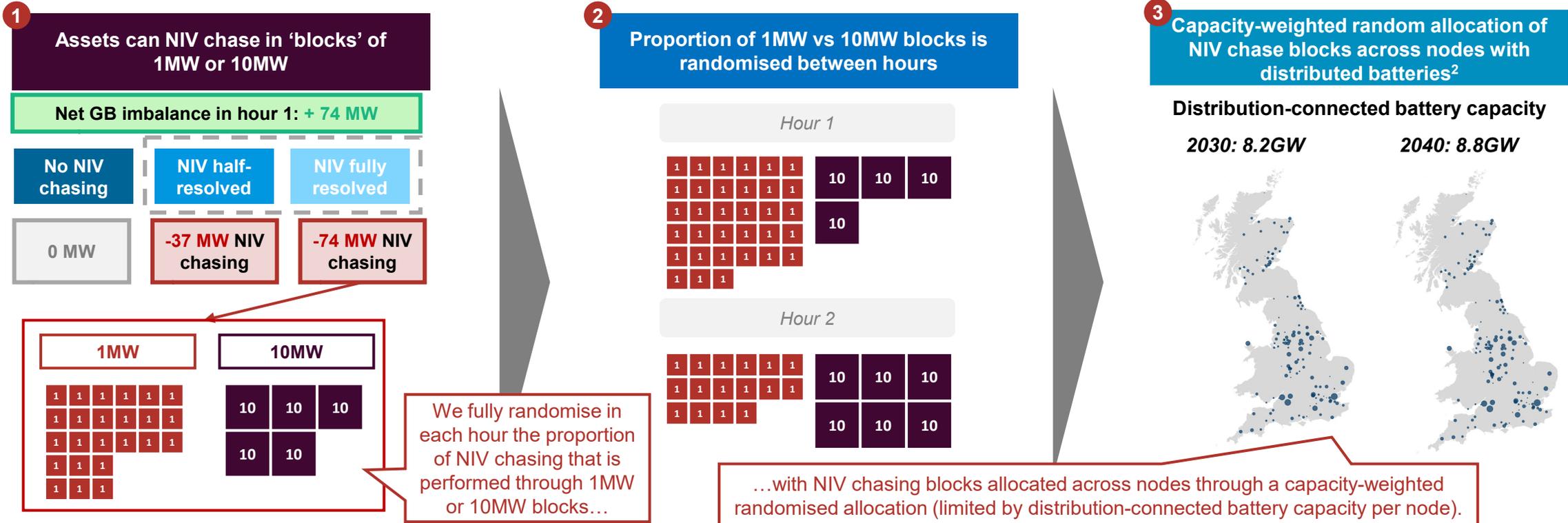
We modelled 3 NIV chasing scenarios and assessed the resulting BM costs impacts

- Empirical data on the level of NIV chasing is not available to NESO or FTI, so we have agreed with NESO that the modelled NIV chase scenarios should be constructed to provide a broad envelope of potential NIV chasing activity and its impact.
- We therefore model a scenario in which NIV chasing does not occur (A), and another in which the NIV is fully resolved by NIV chasing each hour (C). However, when fully resolving the NIV (at GB-aggregate level), nodal-level imbalances can remain in hours when there are intra-GB Tx constraints present (as shown in the figure below). We also model an intermediate theoretical 50% NIV chase scenario (B).
- The focus of this analysis is on how NIV chasing affects the BM actions required to be taken by NESO. Therefore, we do not explicitly model NIV chasing assets. Instead, NIV chasing is modelled by applying increases or decreases in net demand at predefined GSPs relative to DA, representing the system impact of NIV chasing assets charging or discharging more than contracted (explained in more detail in the next slide).
- Importantly, the methodology assumes that NIV chasers have perfect co-ordination and perfect foresight of the size and direction of the net GB-level imbalance in each settlement period (i.e. their combined activity never 'overshoots' the NIV and they do not chase in the 'wrong' way) and by extension NESO has visibility of the level of NIV chasing that will occur. In that regard, our results are conservative with regards to potential additional BM costs that can be incurred due to NIV chasing activity.



NIV chasing is modelled in 1MW and 10MW ‘blocks’ which are allocated to the nodes with distribution-connected batteries

- 1 Very limited empirical data suggests NIV chasers likely adopt varying strategies hour by hour, sometimes ‘chasing’ only a small amount relative to their available capacity, while in other instances creating larger imbalances. This ‘NIV chasing dynamic’ has also been confirmed by NESO’s experience. To capture this dynamic, we model NIV chasing in ‘blocks’ of 1MW or 10MW.
- 2 The proportion of 1MW and 10MW blocks of “NIV chasing” is randomised for each hour.
- 3 Following discussions with NESO, we assume only distribution-connected batteries can NIV chase as these are most likely to represent non-BM registered battery units (BM-registered units are bound by the Grid Code to minimise deviation from their FPNs submitted an hour before RT, making NIV chasing more difficult). NIV chasing activity is distributed across GB in each settlement period through a capacity-weighted random allocation process relative to each node’s distribution-connected battery capacity. The spread of distribution-connected batteries across GB (derived from FES 2024) is broadly even, although with more concentration in the south (as displayed below).¹



Note: (1) There is limited additional distributed battery capacity rollout between 2030 and 2040 while RES capacity and demand increases substantially over this horizon. This results in the hourly NIV occasionally exceeding total distributed battery capacity. In these instances, under the 100% NIV chase scenario, hourly NIV chasing is capped at total distribution-connected battery capacity, such that a small portion of NIV remains. This occurs in 0.1% of hours in 2035 and 0.2% in 2040, such that this assumption does not materially affect conclusions; (2) Size of the discs indicates the level of capacity in a particular location.

The applied methodology results in ‘spiky’ NIV chasing volumes, as shown by an example for the GSP Osbaldwick

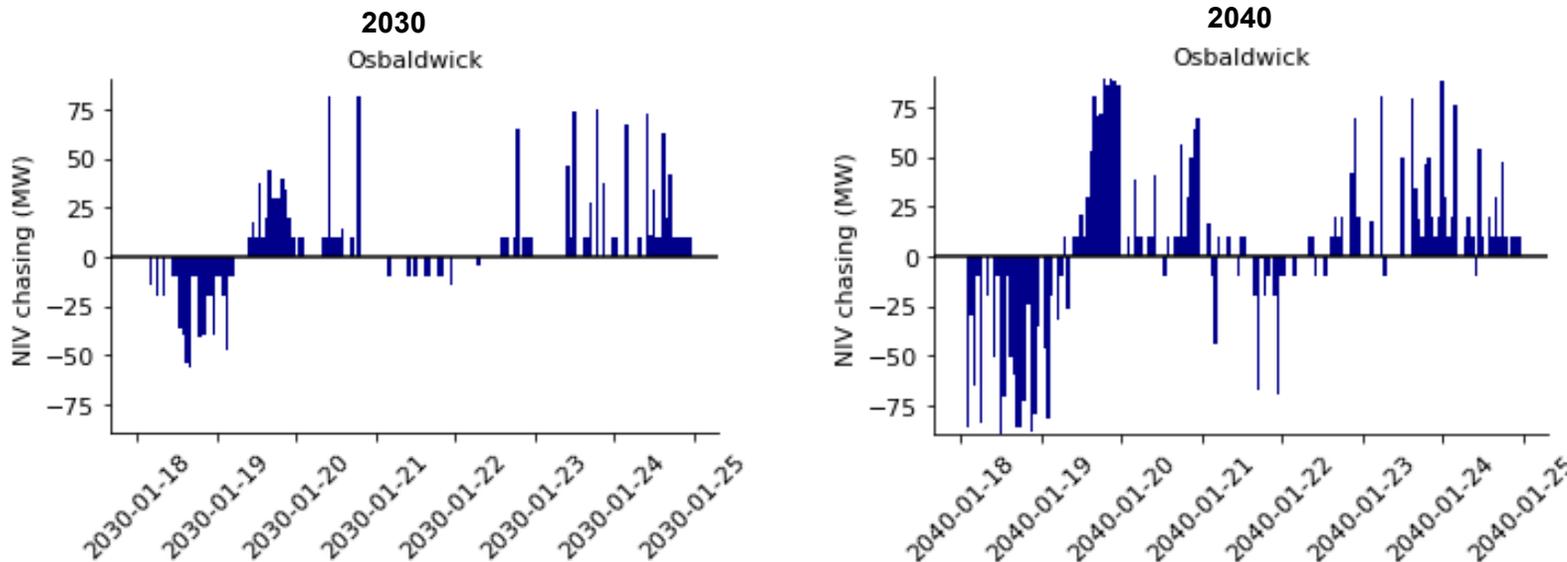
- The charts below show the modelled NIV chasing at the GSP Osbaldwick during an example week in 2030 and 2040.
- Unlike the modelled NIV, which is based on historical data and therefore follows the same profile across modelled years (but is scaled depending on RES capacity/demand), NIV chasing is re-randomised each modelled year.
- In all modelled years, we observe ‘spiky’ NIV chasing profiles, whereby:
 - There are hours where there is no NIV chasing;
 - There are hours where there is small amount of NIV chasing relative to capacity; and
 - In some hours, distribution-connected batteries NIV chase up to their full capacity.¹
- Patterns of NIV chasing are similar across modelled years, but the total volume of NIV chasing is greater in 2040 due to typically greater NIV per ISP.

Distribution-connected battery capacity, GB, 2040²



Total installed battery capacity at Osbaldwick is 90MW

Modelled NIV chasing profile, GSP Osbaldwick, Jan 18 – Jan 25, 100% NIV chasing scenario (MW)

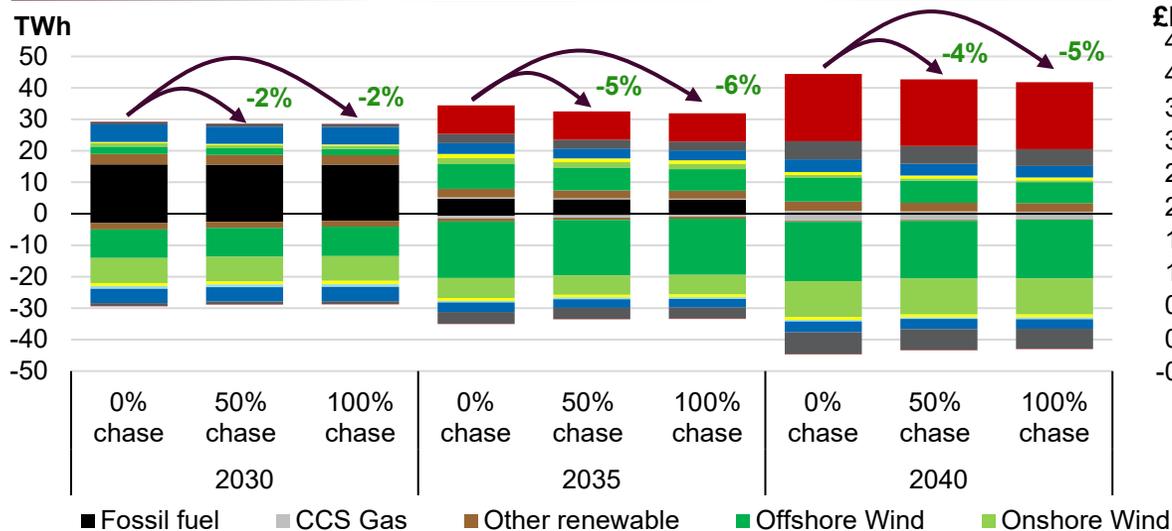


Note: (1) Historical data on hourly imbalance positions for battery units suggests this might be a reasonable representation of NIV chasing strategies, with NESO validating this is a suitable approach for conducting our quantitative analysis. However, empirical NIV chasing activity is not available and historical imbalance positions do not necessarily indicate NIV chasing (units could accidentally be out of balance or be providing broader portfolio balancing). (2) Size of the discs indicates the level of capacity in a particular location.

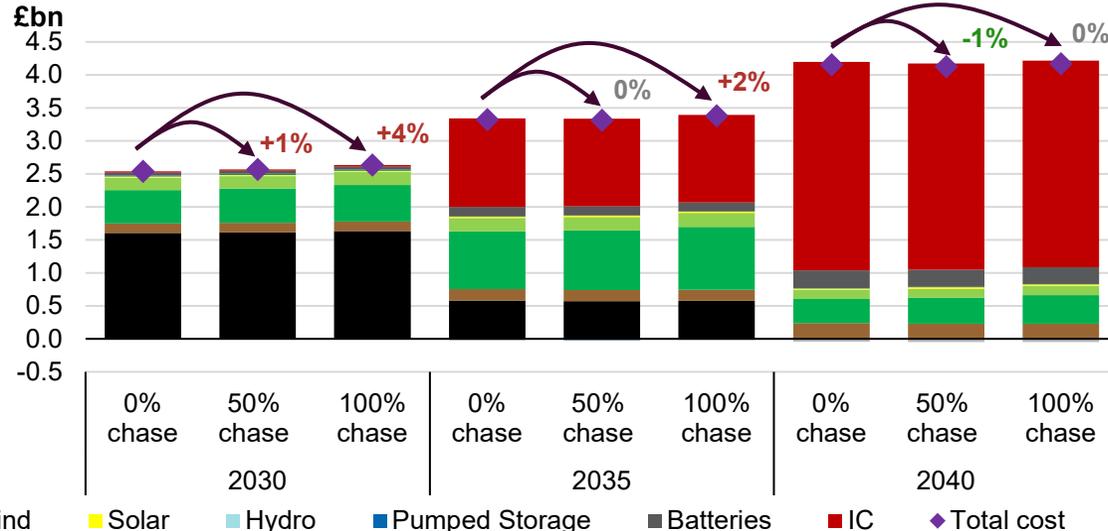
Results

Increasing NIV chasing activity reduces total BM volumes, but this is not met with a corresponding reduction in BM costs

BM volumes by technology, 0%, 50% and 100% NIV chasing scenarios (TWh)



BM costs by technology, 0%, 50% and 100% NIV chasing scenarios (£bn)



- **Annual BM volumes increase across the modelled horizon** independent of the level of NIV chasing due to increased Tx constraints, from c. 30TWh on and off in 2030 to over 40TWh on and off in 2040.
- Considering the role of different technologies, the most important trend is the gradual replacement of constrained-on volumes of fossil generators by constrained-on volumes of ICs, in line with expectations and FTI’s previous work.
- **Increased NIV chasing activity decreases the volume of BM actions in all modelled years** (by 2-5% per annum under 50% NIV chasing and 2-6% per annum under 100% NIV chasing).
- This indicates that the reduction in volume of energy balancing actions due to NIV chasing outweighs potential increases in volume of system balancing actions (outlined in Slide 11).

- **Annual BM costs also increase across the modelled horizon**, independent of the level of NIV chasing, from c. £2.5bn in 2030 to c. £4.2bn in 2040.¹
- **BM costs increase proportionally more than BM volumes**, mostly due to increased need for costlier redispatch actions on ICs (relative to fossil fuels) in later years.
- **The reduction in annual BM volumes with increased NIV chasing activity does not necessarily lead to a reduction in annual BM costs** (rather it leads to a minor increase between £12m and £94m per year with 100% chasing and a change of -£31m to +£29m with 50% chasing). This is for two reasons:
 - The hours in which NIV chasers **reduce BM volumes** are hours with **relatively low BM costs** (i.e. indicating hours with a low level of Tx constraints).
 - Although **less frequent**, in some hours **NIV chasers worsen local imbalances**, which have a **disproportionate effect on BM costs** due to the need for **very costly BM actions** (as the cheaper BM actions are already activated) (see following slides for more detail).

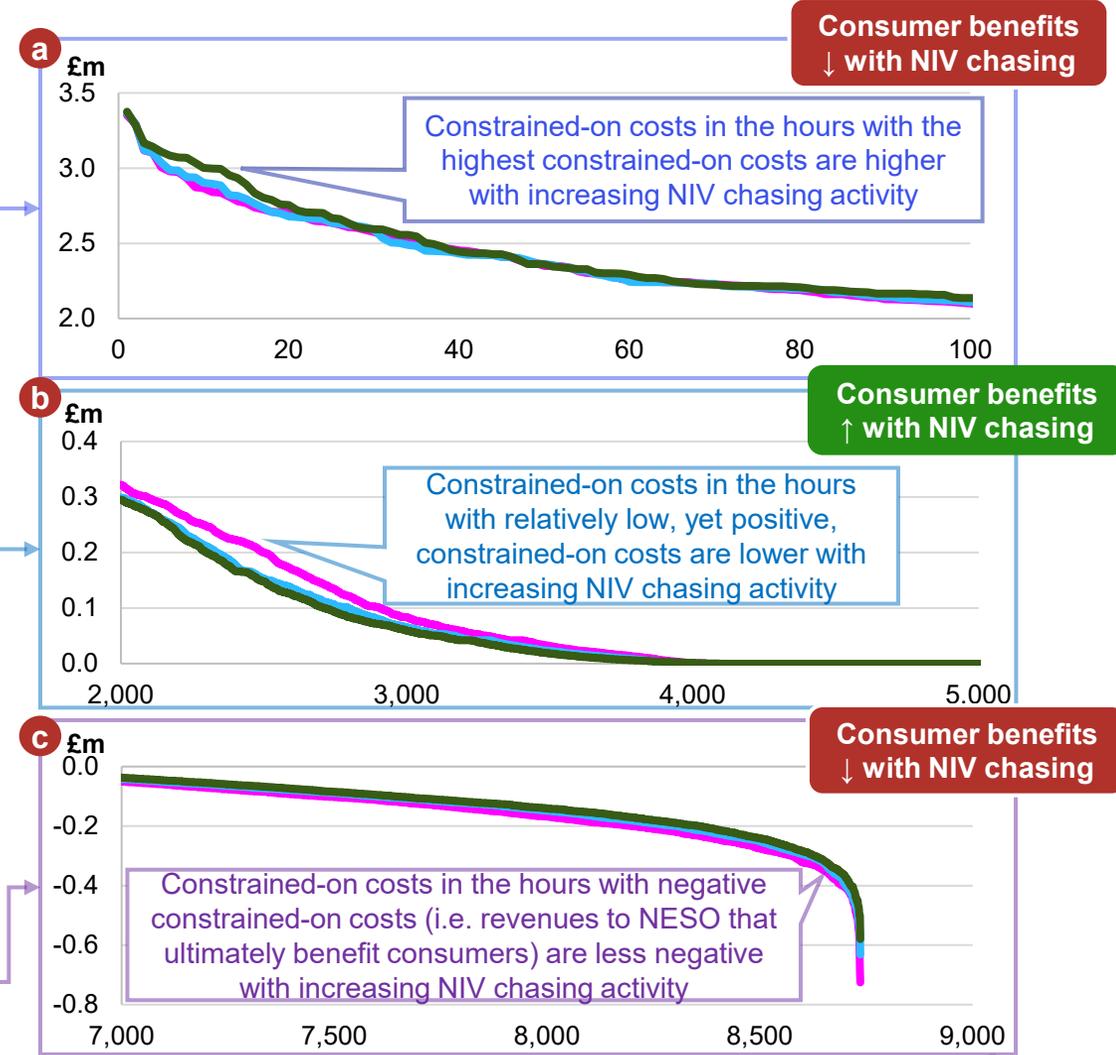
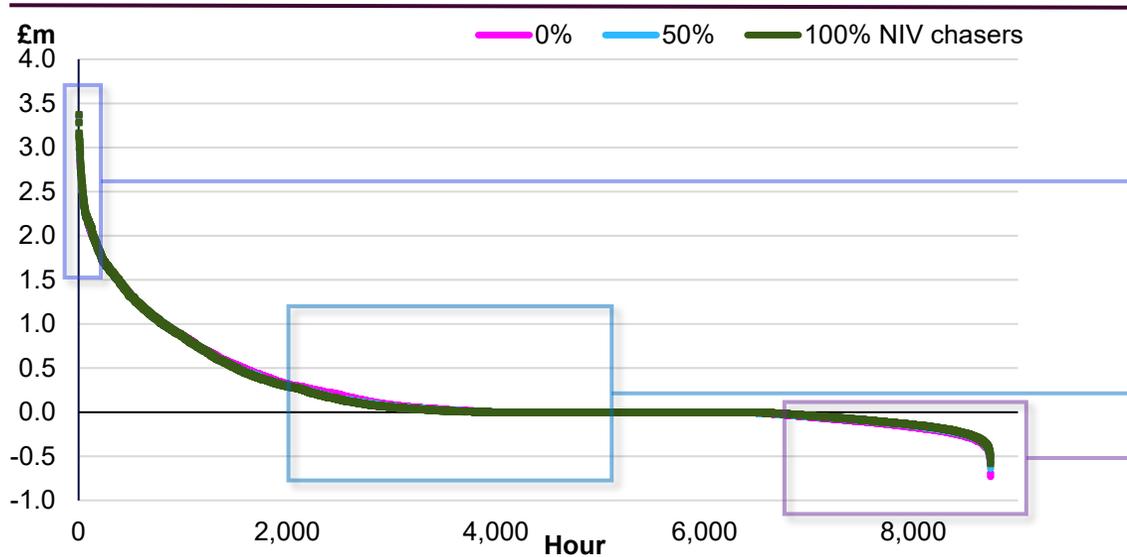
32 Note: (1) Isolating the impact of the volume of Tx constraints and the magnitude of the NIV on BM costs indicates that the impact of growing Tx constraints far outweighs the impact of growing NIV volumes on BM costs over the modelled horizon.

NIV chasing increases costs further in infrequent 'high constrained-on cost hours'

Below we show the hourly constrained-on costs in the BM from high-cost to low-cost hours for the three modelled scenarios in 2035^{1,2}: no NIV chasing, 50% chasing and 100% chasing. The three highlighted snapshots show that:

- a** In hours with high constrained-on costs, BM costs are (even) higher with more NIV chasing activity due to NIV chasers increasing local imbalances.
- b** In hours with low, yet positive, constrained-on costs, NIV chasing reduces BM costs due to reducing the need for constrained-on actions
- c** In hours with negative constrained-on costs, constrained-on costs are slightly less negative with more NIV chasers as NIV chasers reduce the need to constrain-on those assets willing to be constrained-on.³

Duration curve of hourly constrained-on costs (excl. storage)⁴, 2035 - 0%, 50% and 100% NIV chasing scenarios (£m)



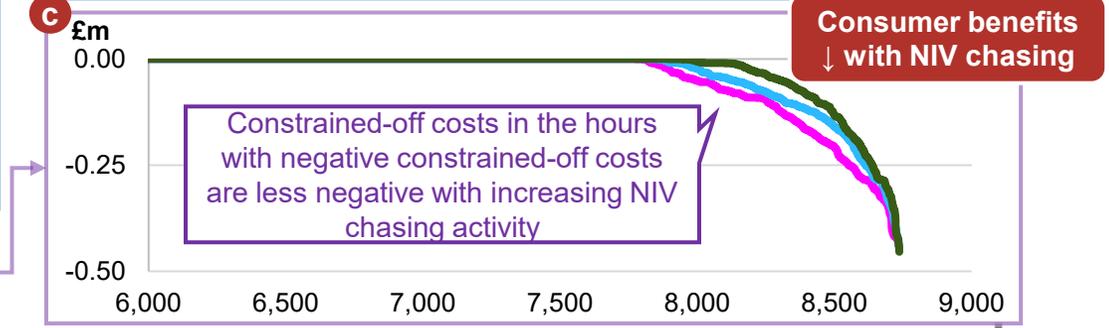
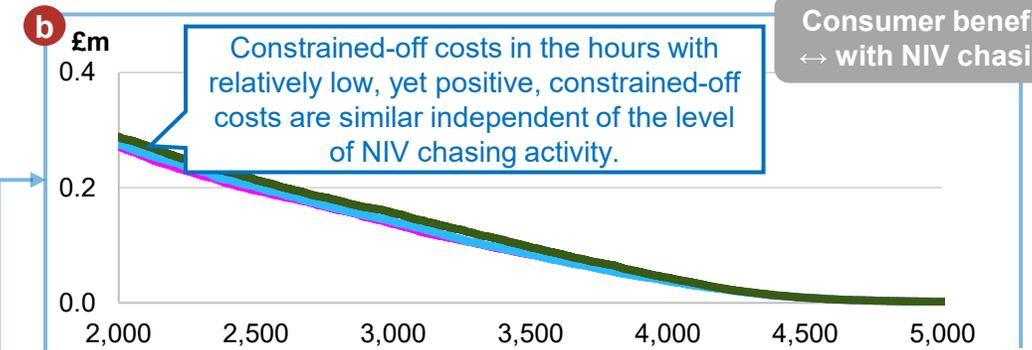
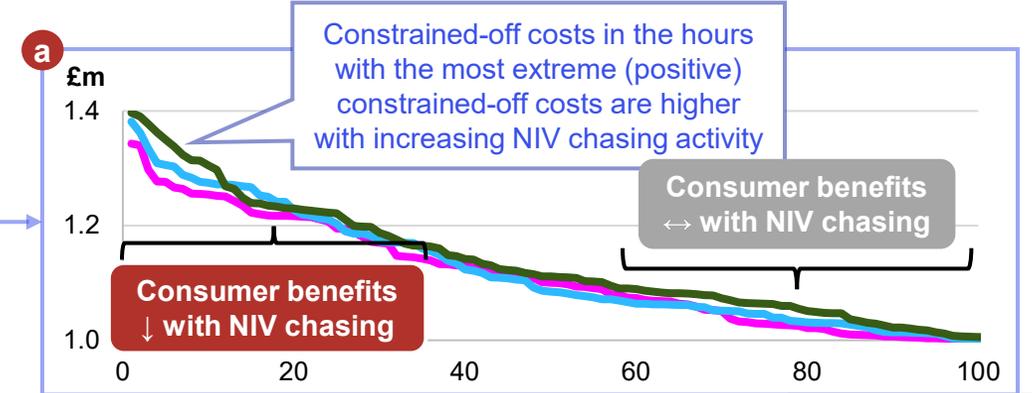
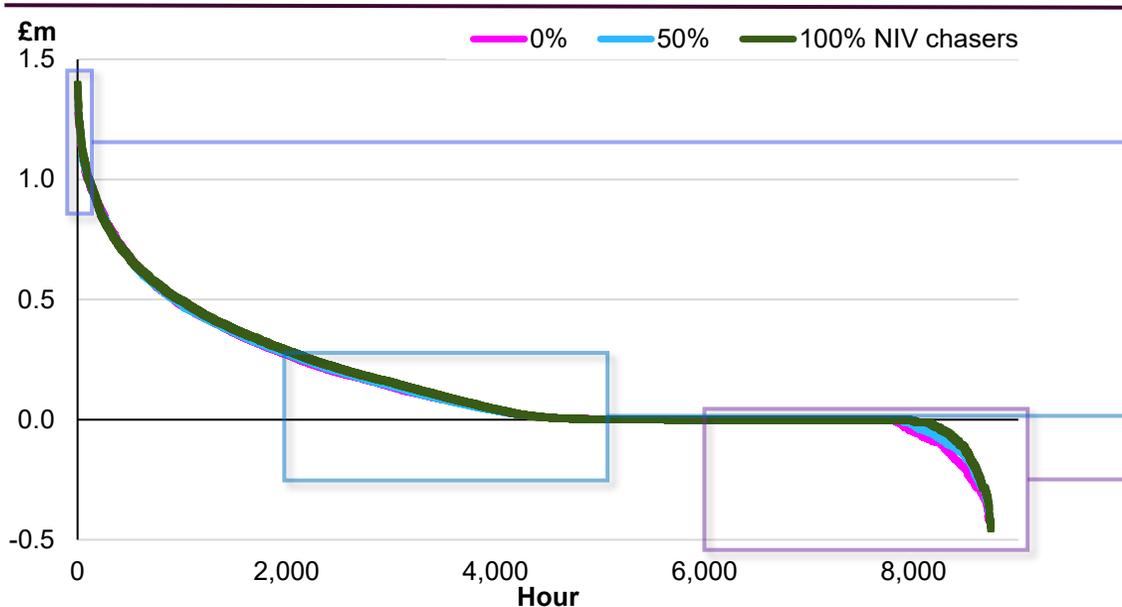
Note: (1) These costs relate to offers submitted in the BM; (2) In Slide 35, we provide a table with the sum of the constrained-on costs of the 20 hours with the highest constrained-on costs for the three modelled years; (3) Assets willing to pay to be constrained-on are renewables under CfD contracts bidding in their CfD strike price minus uplift (see Slide 20), as by being constrained-on they can receive a CfD top-up. Hence, the increase in constrained-on costs under more NIV chasing activity during those hours with negative constrained-on costs is expected to be counterbalanced by lower CfD costs; (4) Storage is excluded here as due to modelling choices we calculate constraint volumes and costs for storage on a 'net' weekly rather than hourly basis.

NIV chasing can reduce the income from infrequent ‘negative constrained-off cost hours’

Below we show the hourly constrained-off costs in the BM from high-cost to low-cost hours for the three modelled scenarios in 2035^{1,2}: no NIV chasing, 50% chasing and 100% chasing. The three highlighted snapshots show that:

- a** In hours with high constrained-off costs, BM costs can increase with more NIV chasing due to NIV chasers increasing local imbalances.
- b** In hours with low, yet positive, constrained-off costs, NIV chasing has limited impact on constrained-off costs.
- c** In hours with negative constrained-off costs, constrained-off costs are less negative with increasing NIV chasing. The NIV chasers reduce the need to constrain off thermal generators which are willing to pay to be constrained off.³

Duration curve of hourly constrained-off costs (excl. storage)⁴, 2035 - 0%, 50% and 100% NIV chasing scenarios (£m)



34 Note: (1) These costs relate to bids submitted in the BM; (2) In Slide 35, we provide a table with the sum of the constrained-off costs of the 20 hours with the highest negative constrained-off costs for the three modelled years; (3) Thermal generators are willing to pay their avoided fuel costs, see Slide 20; (4) Storage is excluded here as due to modelling choices we calculate constraint volumes and costs for storage on a ‘net’ weekly rather than hourly basis.

Across all years, NIV chasing tends to increase the highest hourly constrained-on costs and to reduce the most negative hourly constrained-off costs

Constrained-on costs

- The table on the right shows the **sum of the constrained-on costs in the 20 hours with highest constrained-on costs** in each of the three modelled years and each of the three NIV chasing scenarios.
- The **highest hourly constrained-on costs are observed in 2040**, which is the year with the highest Tx constraint volumes and NIV (for annual results see Slide 32).
- **NIV chasing increases constrained-on costs** in the hours with highest constrained-on costs in all years. This indicates that **NIV chasing has a consistent negative consumer impact** in these 'extreme hours' due to worsening the local imbalance, triggering additional costly system balancing actions.¹

Constrained-off costs

- Performing similar analysis for the **sum of the constrained-off costs in the 20 hours with the most negative constrained-off costs** in each year and chasing scenario shows that constrained-off BM costs in these hours are **most negative in the no NIV chasing scenario**.
- These negative constrained-off BM costs are a **consumer saving**, indicating that **NIV chasing has a consistent negative consumer impact** in these hours (as it reduces the negative costs, i.e. reduces consumer saving).

Constrained-on cost, sum of the top 20 highest hours (£m)

	0% chase	50% chase	100% chase
2030	38.6	39.1 ↑	39.8 ↑
2035	58.1	58.5 ↑	60.0 ↑
2040	72.1	72.4 ↑	73.4 ↑

Constrained-off cost, sum of the 20 most negative hours (£m)

	0% chase	50% chase	100% chase
2030	-9.33	-8.54 ↑	-8.14 ↑
2035	-8.49	-8.19 ↑	-8.09 ↑
2040	-8.84	-8.81 ↑	-8.80 ↑

↑ Increase in BM cost with higher volumes of NIV chasing

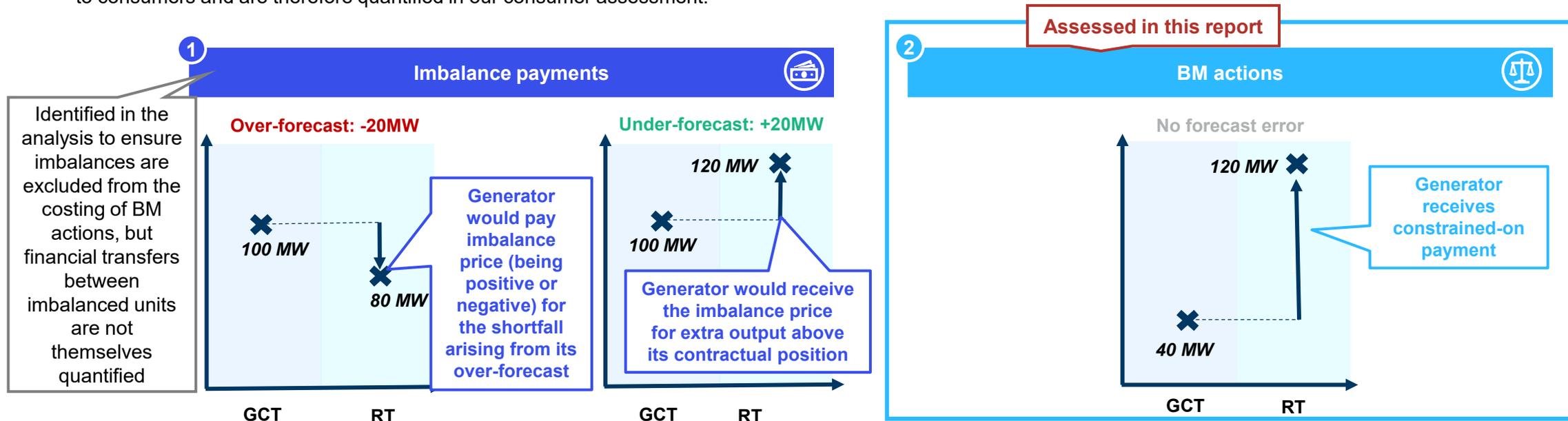
Negative BM costs are a **consumer saving**, therefore less negative costs are a disbenefit of NIV chasing.

Note: (1) NIV chasers were also found to increase the constrained-on volumes in the 20 hours with highest constrained-on volumes. The sum of constrained-on volumes in the top 20 hours with highest constrained-on volumes increases by 0.4% with 50% NIV chasing and 1.9% with 100% NIV chasing (on average across the modelled period), relative to the scenario with no NIV chasing. The highest (forecasted) constrained-on volumes inform upward reserve requirements. While not quantified here, these results suggest NIV chasing could increase requirements for upward reserve, the costs of which would be passed through to consumers. The sum of constrained-off volumes in the 20 hours with the highest constrained-off volumes decreases slightly with increasing NIV chasing (on average by 0.5% for 50% NIV chasing and 1.0% for 100% NIV chasing). Downward reserve costs are typically significantly lower than upward reserve costs.

Appendix

Transfers of NIV settlement costs between imbalanced parties are excluded from the consumer cost assessment

- In the modelling of non-NIV chasing units, we assume that a generator's RT dispatch would only deviate from its GCT schedule for two reasons:
 - The generator's output **changes due to its own forecast error**, i.e. it is positively or negatively imbalanced in RT relative to its FPN at GCT; or
 - The generator's output changes because it is **constrained-on or off by NESO in the BM in order to balance the system** (either for energy balancing reasons or to resolve system constraints).
- In the former case, this is a **unit-driven deviation** from the generator's FPN at GCT. We assume for simplicity that each generator's FPN is equal to its contractual position at GCT, and there is no change in contractual positions post-GCT. This means that each generator is exposed to **the single imbalance price** for its change in output, with direct financial transfers between units that are short and long in each ISP. Depending on the hour, the net difference between the amount paid by units that are short and received by those that are long can be net positive or negative, and on an annual basis can result in a surplus, the so-called Residual Cashflow Reallocation Cashflow (RCRC), distributed back across Balancing and Settlement Code parties.¹ **We do not model changes in the RCRC due to NIV chasing in this assessment.**
- In the latter case, these actions are considered NESO BM actions and result in balancing costs, which are remunerated as pay-as-bid. These total BM costs are passed through to consumers and are therefore quantified in our consumer assessment.



Glossary

Glossary

Acronym	Definition
BM	Balancing Mechanism
BMU	Balancing Mechanism Unit
CfD	Contract for Difference
CP2030	Clean Power 2030
CY	Climate Year
DA	Day-ahead
DE	Distributed Energy
DESNZ	Department for Energy Security and Net Zero
DNO	Distribution Network Operator
ENTSO-E	European Network of Transmission System Operators for Electricity
ERAA	European Resource Adequacy Assessment
FES	Future Energy Scenarios
FF&R	Further Flex & Renewables
FPN	Final Physical Notification
FTI	FTI Consulting LLP
GB	Great Britain
GCT	Gate Closure Time

Acronym	Definition
GSP	Grid Supply Point
HT	Holistic Transition
IC	Interconnector
ID	Intraday
ISP	Imbalance Settlement Period
NESO	National Energy System Operator
NIV	Net Imbalance Volume
NT	National Trends
RCRC	Residual Cashflow Reallocation Cashflow
REMA	Review of Energy Market Arrangements
RES	Renewable Energy Sources
ROC	Renewable Obligation Certificate
RT	Real Time
SRMC	Short-run Marginal Cost
Tx	Transmission
TYNDP	Ten-Year Network Development Plan

